Influence of Helminth Parasite Exposure and Strategic Application of Anthelmintics on the Development of Immunity and Growth of Swine

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INFLUENCE OF HELMINTH PARASITE EXPOSURE AND STRATEGIC APPLICATION OF ANTHELMINTICS ON THE DEVELOPMENT OF IMMUNITY AND GROWTH OF SWINE[1,2]

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ABSTRACT

Infection of pigs with the intestinal roundworm parasite *Ascaris suum* and strategic application of anthelmintic drugs during the growing phase of development were observed for specific effects on 1) development of immunity in feeder pigs and 2) growth rate during the finishing phase. Management treatments included maintenance in a parasite-free concrete environment, maintenance in a concrete environment and inoculation with 1,000 infective *A. suum* eggs every other day over a 52-d period, and maintenance on a dirtlot contaminated with *A. suum* and *Trichuris suis* eggs. Within each management environment, pigs were either untreated, treated with ivermectin or treated with fenbenzadole at strategic times during parasite exposure. Protective immunity, assessed by a challenge inoculation with *A. suum* eggs following management treatments, was not affected by ivermectin or fenbenzadole treatment during exposure, but adult worm burdens were reduced and the pattern of *A. suum* larval antigen serum antibody responses were different from those in control pigs not treated with drugs. Exposure to *A. suum* and treatment with anthelmintics during the growing phase reduced adult worm burdens following the finishing phase of growth. Rate, but not efficiency, of gain was significantly improved by anthelmintic treatment following natural exposure to parasites. Strategic treatment of pigs with anthelmintics following inoculation with *A. suum* eggs in a concrete management environment had no effect on rate of gain. Results suggest that natural exposure to parasites during the growing phase without therapeutic treatment causes permanent damage to growth potential.
(Key Words: Pigs, Parasites, Anthelmintics, Management.)

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Introduction

Swine internal parasitism causes unthriftiness and poor growth performance (Biehl, 1982; Stewart et al., 1985). The primary methods of control have been the use of highly effective anthelmintic drugs and minimizing parasite exposure in well-managed confinement housing operations (Murrell, 1986). But these methods have not always succeeded in preventing herd infection with the large roundworm parasite of swine, *Ascaris suum* (Biehl, 1982). Several studies reported poor weight gain (Spindler, 1947), digestion and absorption of nutrients in pigs infected with *A. suum* (Zimmerman et al., 1973; Stephenson et al., 1980; Forsum et al., 1981; Hale et al., 1985). Infection and subsequent larval migration in young pigs can have both immediate (Jakovljevic, 1975; Stewart et al., 1984) and long-term effects on growth performance (Froe, 1982; Nilsson, 1982). However, others have argued

[1]Mention of a trade name, proprietary product or vendor does not constitute a guarantee or warranty of the product by USDA or imply its approval to the exclusion of other products or vendors that also may be suitable.

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TABLE 1. EXPERIMENTAL DIET

Ingredient	% of Total
Ground corn	73.98
Dehulled soybean meal	17.90
Alfalfa meal	5.00
Dicalcium phosphate	1.55
Calcium carbonate	.72
Iodized salt	.50
Trace mineral mix[a]	.10
Vitamin premix[b]	.05
Selemiun premix[c]	.05

[a]Provided the following micronutrients (ppm) per kg complete diet: Mn, 100; Fe, 100; Cu, 10; Co, 1; I, 3; Zn, 100.

[b]Provided the following per kg of diet: vitamin A, 4,400 IU; vitamin D, 800 IU; riboflavin, 8.8 mg; pantothenic acid, 17.6 mg; niacin, 30.8 mg; vitamin B_{12}, 44 μg; choline, 220 mg; vitamin E, 11 IU.

[c]Premix provided .1 mg Se per kg of complete diet.

that there are no discernible effects of *A. suum* infection acquired during the finishing phase of growth, >60 kg (Nilsson, 1982).

This study examined the immune status of feeder pigs exposed to parasites either naturally on dirt or by continual experimental inoculation, along with the effects of strategic application of anthelmintics. The growth performance of similarly treated pigs during the growing period was evaluated subsequently under uniform conditions of housing and nutrition.

Materials and Methods

A total of 96 crossbred pigs (73 from Yorkshire × Duroc sows and Yorkshire × Duroc boars and 23 from Hampshire sows and Yorkshire boars) and 12 purebred Yorkshire pigs were used for these studies. Sows and boars were maintained in an open dirtlot with a concrete slab feeding area. Animals were treated with an anthelmintic at 60-d intervals. Sows farrowed in concrete pens that were cleaned by daily washing. Between farrowing intervals, pens were disinfected with a liquid lye solution. Periodic monitoring of tracer pigs farrowed in this management system showed that gastrointestinal nematode infection rates were <1% of pigs sampled. Pigs were born over a 3-wk period in 16 litters. Routine litter management included ear-notch identification and treatment with iron within 3 d postpartum. Pigs were weaned at 5 wk and were fed once daily a corn-soybean meal formulation containing 16% crude protein and vitamins and minerals that exceeded NRC (1979) guidelines (Table 1); water was available at all times. Males were castrated 1 wk postweaning. The experiment was started with pigs between 6 and 10 wk of age.

The experimental design consisted of two phases. Phase 1 (Table 2) tested nine groups, designated A through I, of 12 pigs each arranged in a 3 × 3 factorial treatment array. Pigs were weighed and assigned to experimental groups to provide a balanced weight, sex (minimum of six barrows per treatment cell), breed and litter distribution among the groups. Pigs in Groups A, D and G (Table 2) were maintained in confinement on concrete flooring free of helminth (worm) parasite exposure (Urban et al., 1988); pigs in Groups B, E and H were maintained similarly, but were inoculated orally every other day through d 52 with

TABLE 2. EXPERIMENTAL DESIGN (DAYS 0 TO 52): PIG EXPOSURE TO PARASITE INFECTION AND ANTHELMINTIC TREATMENT[a]

	Parasite exposure		
Anthelmintic treatment	None (helminth free in confinement)	*A. suum* inoculated (1,000 eggs every 2 d for 52 d)	Naturally exposed (contaminated dirtlot for 52 d)
None	A	B	C
Ivermectin[b] (.3 mg/kg BW)	D	E	F
Fenbendazole[c] (3.0 mg/kg BW)	G	H	I

[a]All groups had 12 pigs each.

[b]All pigs treated on d 6; on d 46 six barrows were randomly selected from each group, segregated and treated with anthelmintic. These pigs were used for Phase 2.

[c]All pigs treated on d 6, 7 and 8; on d 46, 47 and 48 six barrows were randomly selected from each group, segregated and treated with anthelmintic. These pigs were used for Phase 2.

1,000 infective *Ascaris suum* eggs (Urban et al., 1981) for a total of 26 inoculations. Pigs in Groups C, F and I were exposed naturally to *A. suum* eggs on a contaminated dirtlot through d 52 (Urban et al., 1988). Parasitological examination of pigs at the end of the experiment revealed that *T. suis* eggs were present on this lot.

During Phase 1, all pigs in Groups A, B and C received no anthelmintic drugs. Pigs in Groups D, E and F were injected subcutaneously with Ivomec®[5] (1% ivermectin) at a dosage of .3 mg/kg body weight on d 6; one-half of the pigs from Groups D, E and F (barrows assigned to Phase 2 were segregated for the second anthelmintic treatment) received a second injection on d 46. All pigs in groups G, H and I were fed Safe-Guard Premix®[6] (4% fenbenzadole) at a dosage of 3.0 mg/kg body weight on three successive days, d 6 through 8, and one-half of the pigs from Groups G, H and I (barrows assigned to Phase 2 were segregated for the second anthelmintic treatment) received a second treatment on d 46 through 48 after initial parasite exposure.

Blood samples (10 ml) were taken weekly from the vena cava and serum was collected and stored at –20°C until used. Serum antibody levels to parasite antigens were detected in individual samples by a triple enzyme-linked immunosorbant assay (Urban et al., 1988). Parasite antigens were derived from the conditioned-media of cultures of second-stage *A. suum* larvae that had developed to the third stage in vitro (Urban and Romanowski, 1985) and was designated as L2, L3 antigen. The level of serum antibody was expressed as an average of individual absorbance readings (450 nm) taken for each serum sample after a dilution of 1:100 (Urban et al., 1988).

Protective immunity to a challenge exposure to infective *A. suum* eggs was determined for one-half the pigs in all groups from Phase 1 that were not included in Phase 2 by quantitating the number of migrating larvae in the lungs of pigs 7 d after an oral challenge inoculation with 10,000 eggs (Urban et al., 1988) that began on d 52. Adult worm burdens were determined concurrently by examination of the screened contents of the small intestines for *A. suum* (Douvres et al., 1969) and visual examination of the cecal mucosa for *T. suis*.

Phase 2 extended from d 53 to d 109, when measurements of average daily gain (ADG) were taken. Six barrows were selected randomly from each of Groups A through I from Phase 1 that had not been challenge-exposed to 10,000 *A. suum* eggs, were relocated to a concrete facility and were placed in pens with slotted cement floors, two pigs per pen. These facilities were steam-pressure cleaned and treated with liquid lye. The residual level of parasite contamination was unknown. Pigs had ad libitum access to the standard diet (Table 1). Feed intake, adjusted for spillage, and body weights were taken at 14-d intervals for 8 wk. One week before slaughter, the pigs were challenge-exposed to 1,000 *A. suum* eggs orally and the livers subsequently were examined and recorded photographically for general liver pathology. Liver "milk-spots" (Roneus, 1966) on the surface were counted and the degree of fibrosis was noted.

Data were analyzed as a randomized block design by least squares procedures using the General Linear Models routine of SAS (Barr et al., 1976). Significance between environment and anthelmintic treatment subclasses were separated by Duncan's comparison.

Results and Discussion

Pigs that were kept free from parasite exposure during Phase 1 of the experiment (Groups A, D and G) did not show an increase in serum antibody to *A. suum* L2, L3 antigens over the 7 wk sampled (Figure 1A). In contrast, pigs in all groups that were parasite-exposed had demonstrable antibodies to parasite antigens after 2 wk of exposure (Figures 1B and 1C). The absorbance values in the ELISA for sera from pigs that were exposed experimentally to *A. suum* (Figure 1B; Groups B, E and H) generally were higher than those for pigs exposed naturally (Figure 1C; Groups C, F and I); however, the pattern of the response was similar. Pigs that were parasite-exposed experimentally but not treated with anthelmintic (Figure 1B; Group B) showed a biphasic antibody response with peak levels at d 21 and d 35 after initial parasite exposure. Pigs that were parasite-exposed experimentally and treated with fenbenzadole had a similar pattern (Figure 1B; Group H) but clearly at a lower level than Group B; pigs from the

[5]Purchased from MSD-AGVET, Rahway, NJ.

[6]Obtained from Hoechst-Roussel Agri-Vet Co., Sommerville, NJ.

ivermectin-treated group (Figure 1B; Group E) had a rising antibody level but one that peaked only at d 35. The serum antibody patterns of those pigs that were exposed naturally (Figure 1C) and either treated or not treated with anthelmintic were similar to their counterparts that had been exposed experimentally (Figure 1B).

Protective immunity to migrating parasitic larvae had developed in all parasite-exposed pigs (Table 3) because few if any larvae (<20) were detected in their lungs following a challenge exposure to 10,000 *A. suum* eggs (Groups B, C, E, F, H and I). Pigs from control groups that had not been parasite-exposed previously had relatively large numbers of larvae in their lungs after inoculation with 10,000 eggs; however, the ivermectin-treated group (D) had significantly fewer larvae than did the non-drug-treated and fenbendazole-treated groups, A and G, respectively.

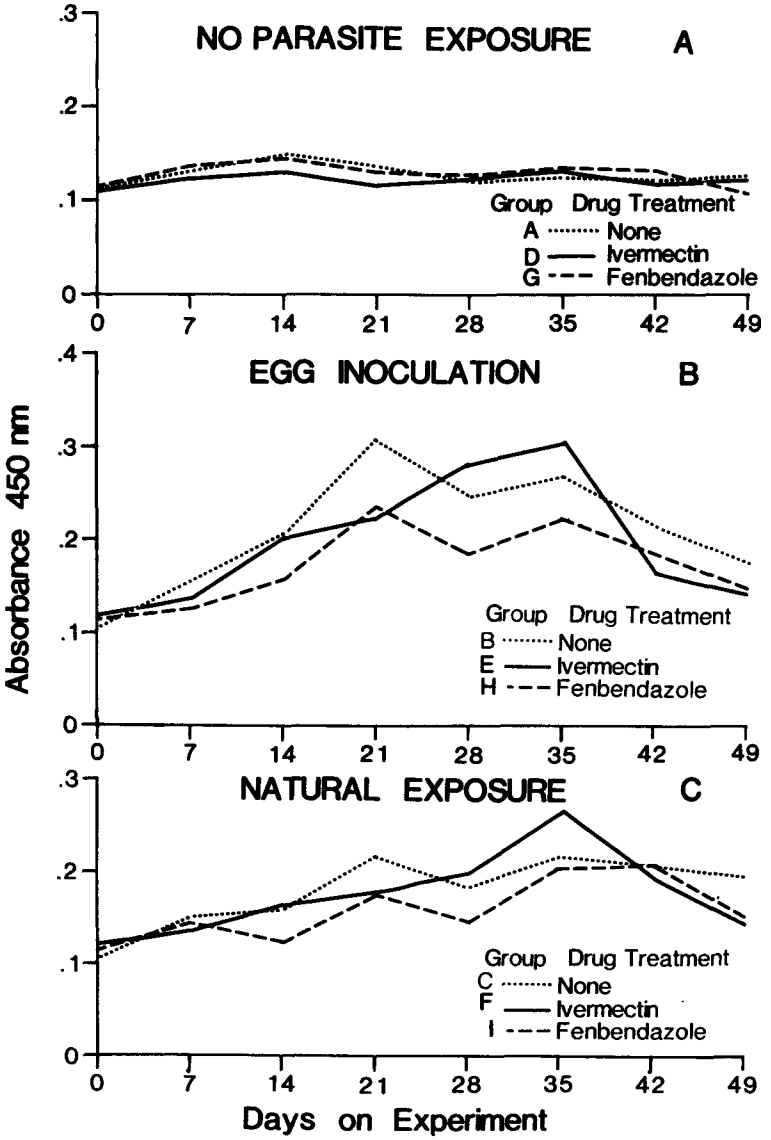

Figure 1. Level of serum antibody to *Ascaris suum* larval antigens in weekly serum samples following no parasite exposure (A), experimental inoculation with 1,000 eggs every other day, 26 times (B), or natural exposure on a dirtlot (C). Swine antibody is assayed using a rabbit anti-swine heavy and light chain IgG. Test serum samples were diluted 1:100 and the absorbance was read after 10 min at 450 nm.

TABLE 3. *ASCARIS SUUM* LARVAE IN THE LUNGS FOLLOWING CHALLENGE INOCULATION WITH 10,000 EGGS (PHASE 1)[a]

Anthelmintic treatment	Parasite exposure: None	*A. suum* inoculated	Naturally exposed
None	1370 ± 209[b] (A)[c]	8 ± 5 (B)	2 ± 2 (C)
Ivermectin	817 ± 195[d] (D)	0 (E)	0 (F)
Fenbendazole	1402 ± 277 (G)	0 (H)	0 (I)

[a]One or two pigs per day for a total of six pigs from each group that were challenge-exposed once on either d 52, 53, 54 or 55 after initiation of the experiment and necropsied 7 d later. Anthelmintic treatment had been administered on d 6 (ivermectin) or d 6, 7 and 8 (fenbendazole) and parasite exposure had been through d 52.

[b]Values are the number of larvae recovered from the lungs ± SEM.

[c]Letters designate groups treated as shown in Table 2.

[d]Less ($P < .05$) than groups A and G but greater ($P < .05$) than groups B, C, E, F, H and I.

Adult worm recoveries indicated that a parasite burden had become established in the intestines during the period of parasite exposure (Table 4). None of the pigs from helminth-free treatment groups (A, D and G) had adult worms. This verified that the level of helminth exposure in the concrete pens used during Phase 1 was relatively low. Pigs inoculated experimentally with *A. suum* eggs had only *A. suum* adults: the non-drug-treated group (B) averaged more worms than the anthelmintic-treated groups, E (ivermectin) and H (fenbendazole). Pigs from the naturally exposed groups (C, F and I) had low numbers of *A. suum* adults but had moderate and similar numbers of *T. suis* adults.

TABLE 4. ADULT *ASCARIS SUUM* AND *TRICHURIS SUIS* RECOVERED FROM THE SMALL INTESTINE AND CECUM (PHASE 1: PROTECTIVE IMMUNITY)[a]

Anthelmintic treatment	Parasite exposure: None	*A. suum 1989* inoculated	Naturally exposed
None			
A. suum	0	31 ± 10 (5/6[b])	2 ± 1 (3/6)
T. suis	0 (A)[c]	0 (B)	21 ± 11 (C)
Ivermectin			
A. suum	0	.5 ± .5 (1/6)	0
T. suis	0 (D)	0 (E)	17 ± 8 (4/6) (F)
Fenbendazole			
A. suum	0	6 ± 4 (2/6)	.3 ± .2 (2/6)
T. suis	0 (G)	0 (H)	22 ± 7 (6/6) (I)

[a]Pigs challenge-exposed and necropsied for lung larvae (Table 3) were also necropsied for adult worms in the small intestine and cecum. Number of adults ± SEM. Anthelmintic treatment had been administered on d 6 (ivermectin) or d 6, 7 and 8 (fenbendazole) and parasite exposure had been through d 52.

[b]Number of infected pigs in each subclass.

[c]Letters designate groups treated as shown in Table 2.

TABLE 5. ADULT *ASCARIS SUUM* RECOVERED FROM THE SMALL INTESTINE AT NECROPSY (PHASE 2)[a]

Anthelmintic treatment	Parasite exposure		
	None	*A. suum* inoculated	Naturally exposed
None	2.2 ± .8 (6/6[b]) (A)[c]	16.3 ± 7.2 (6/6) (B)	20.2 ± 9.4 (4/6) (C)
Ivermectin	4.8 ± 4.0 (4/6) (D)	.5 ± .5 (1/6) (E)	.4 ± .2 (1/6) (F)
Fenbendazole	.3 ± .2 (2/6) (G)	2.8 ± 1.8 (2/6) (H)	6.3 ± 2.7 (5/6) (I)

[a]Six barrows from each group taken from Phase 1 were anthelmintic treated on d 46 (ivermectin) or on d 46, 47 and 48 (fenbendazole) and parasite-exposed through d 52, and then placed in confinement on d 53 for the growth study. One or two pigs per day for a total of six pigs were killed on d 127, 130, 134 or 139, and worms were recovered. All pigs had been challenge-inoculated with 1,000 *A. suum* eggs 7 d before necropsy. No *T suis* were detected. Number of adults ± SEM.

[b]Number of infected pigs in each subclass.

[c]Letters designate groups treated as shown in Table 2.

Pigs remaining from Phase 1 (barrows) that had received a second similar anthelmintic treatment before re-exposure to parasites and analysis for growth characteristics in Phase 2 were examined for their adult worm burdens at slaughter (Table 5). All pigs had been challenge-inoculated with 1,000 *A. suum* eggs 7 d before slaughter to evaluate liver reactivity to infection. Control groups that had not been parasite-exposed in Phase 1 did have low numbers of *A. suum* worms at the end of Phase 2. This indicated that the concrete pens and(or) feeders used in Phase 2 were contaminated with infective *A. suum* eggs, and steam-cleaning and lye treatment of the flooring had been ineffective in removing the contamination. However, the highest worm burdens were detected in the experimentally and naturally infected pigs that had never received anthelmintics (Groups B and C). The fewest adult worms were observed in the ivermectin-treated groups, E and F, and the fenbendazole-treated pigs (Groups H and I) had an intermediate level. Adult *T. suis* was not detected in any of the pigs at the end of Phase 2.

The appearance of livers at the time of slaughter, 7 d after a challenge exposure to 1,000 *A. suum* eggs, can be summarized generally as follows: pigs in Groups A, D and G that were not parasite-exposed in Phase 1 had greater than 100 to 150 intense, raised, nodular lesions with extensive surrounding intralobular fibrosis. Those pigs that had been parasite-exposed (Groups B, C, E, F, H and I) had fewer than 25 to 50 relatively flat lesions; the remainder of the liver surface was normal or exhibited lesions that were faint and apparently were disappearing.

Pigs (barrows) analyzed for growth performance in Phase 2 of the experiment had no significant difference in mean body weights among the groups initially or at d 14 after the start of Phase 2 (Table 6). However, the body weight of pigs in Group C, exposed naturally to parasites but not treated with anthelmintic, differed ($P < .05$) from Groups F and I at 28, 42 and 56 d into Phase 2.

Analysis of the average daily gains (ADG) of pigs on Phase 2 showed that all pigs reared completely in confinement on concrete (Groups A, B, D, E, G and H), regardless of parasite exposure or anthelmintic treatment, had similar ADG (Figure 2). All pigs maintained on dirt in Phase 1 (Groups C, F and I) had lower ADG than all other pigs in the study after they were moved indoors on concrete for Phase 2. However, the anthelmintic-treated groups (F and I) that initially had been parasite-exposed on dirt had ADG that were lower but not significantly different from those of pigs reared completely in confinement on concrete. Pigs in Group C that were naturally exposed to parasites and not treated with anthelmintic had ADG that were lower ($P < .05$) than those of all other pigs, including those that had been naturally exposed to parasites on dirt but treated with anthelmintic (Groups F and I). Feed efficiencies (Table 6)

TABLE 6. EFFECT OF PARASITE EXPOSURE AND STRATEGIC APPLICATION OF ANTHELMINTICS ON AVERAGE DAILY GAIN (ADG) AND FEED EFFICIENCY (F/G) (PHASE 2)[a]

Anthelmintic treatment	Parasite exposure: None	*A. suum* inoculated	Naturally exposed
None			
Wt, kg[b]	29.3 ± 1.9	29.2 ± .9	30.8 ± 1.9
ADG, g	978 ± 28	966 ± 34	722 ± 23[c]
F/G	2.96 ± .26 (A)[d]	3.11 ± .06 (B)	3.34 ± .10 (C)
Ivermectin			
Wt, kg	30.3 ± 1.9	28.6 ± 1.6	32.4 ± 4.5
ADG, g	1036 ± 41	961 ± 43	890 ± 64
F/G	2.86 ± .07 (D)	3.05 ± .07 (E)	3.18 ± .04 (F)
Fenbendazole			
Wt, kg	30.2 ± 1.3	27.4 ± 1.6	35.0 ± 2.9
ADG, g	943 ± 21	1019 ± 34	942 ± 63
F/G	3.01 ± .19 (G)	3.08 ± .07 (H)	2.81 ± .02 (I)

[a]Values represent the mean ± SEM of six and three observations per treatment cell for ADG and F/G, respectively, over a 56-d period. Barrows from Phase 1 were anthelmintic-treated on d 46 (ivermectin) or d 46, 47 and 48 (fenbendazole) and exposed to parasites for an additional 7 d before necropsy. All pigs were housed in partially slotted concrete floor pens and offered feed and water ad libitum.

[b]Body weight at initiation of Phase 2.

[c]Significantly ($P < .05$) different from groups F and I for body weight.

[d]Letters designate groups treated in Phase 1 as shown in Table 2.

comparing the different management and pharmacological treatments were uniformly good and not affected ($P > .05$).

Discussion

Swine production methods in the U.S. have shifted to a greater emphasis on large-scale confinement-managed production schemes (Stewart et al., 1985). This shift, when coupled with the availability of highly effective anthelmintic drugs (Biehl, 1986; Marchiondo and Szanto, 1987), a clear understanding of the epidemiology and pathogenesis of the major swine helminth parasites (Murrell, 1986) and a growing knowledge of the immunobiology of

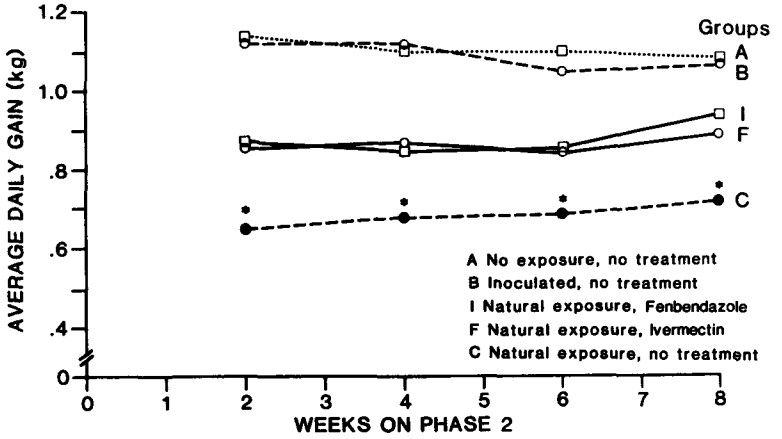

Figure 2. Average daily gain (ADG) is expressed in kg/d. Weights were taken after four, 2-wk intervals. Feed intake was recorded daily after adjusting for spillage. Groups D, E, G and H were similar to groups A and B, and for clarity were not shown.

helminth infections (Urban, 1985) offers an opportunity to apply integrated control strategies to a complex, costly and persistent swine disease problem, gastrointestinal parasitism. An attempt was made in this study to examine the immediate effects of parasite exposure, under different conditions of swine management and anthelmintic dosing, on the development of immunity to infection in feeder pigs. The long-term effects of these treatments on growth performance then was evaluated in finishing pigs under uniform conditions of management and nutrition. The results clearly indicate that 1) the development of immunity to infection is not influenced by a short interval of anthelmintic dosing with ivermectin or fenbendazole, 2) management conditions that allow chronic natural exposure of feeder pigs to helminth parasites on dirt have long-term deleterious effects on growth performance and 3) these latter effects may be corrected by appropriate anthelmintic treatment.

The role of immunity in this scheme is ambiguous. All pigs in Phase 1 of the study developed high levels (>99%) of protective immunity to a challenge-exposure to 10,000 infective *A. suum* eggs following chronic experimental or natural exposure (Table 3). Neither drug appeared to affect the development of protective immunity, because no larvae were detected in the lungs of anthelmintic-treated, parasite-exposed pigs, compared with high larval recoveries in drug-treated controls not exposed to parasites following a challenge exposure to 10,000 eggs (Table 3). However, there was a reproducible shift in the serum antibody response of parasite-exposed pigs that were treated with anthelmintic (Figure 1). This could be a product of differences in drug pharmacokinetics and route of treatment. Fenbendazole-treated pigs had a lower level of serum antibody to parasite antigens over the course of exposure than parasite-exposed pigs not treated with drugs. The fact that fenbendazole was administered orally and was part of the enteral milieu and absorbed locally for three successive days could have reduced larval penetration of intestinal tissues and subsequent migration. This could have effectively provided a lower antigenic stimulus for antibody production during the initial phase of immune induction of the host. Subsequent development of immune protective mechanisms induced by migrating larvae unaffected by diminishing drug concentrations then could have prevented the further development of reinfecting larvae in a manner comparable to that developing in parasite-exposed, non-treated pigs. These effects would result in a generally lower antibody response following both experimental and natural infection and fenbendazole treatment. In contrast, ivermectin injected subcutaneously could result in relatively greater killing of larvae parenterally, and degenerating larvae subsequently could act as depots of antigens for continual stimulation of the immune system. This could explain a serum antibody response that peaked later and at a higher level than for other parasite-exposed groups (Figure 1). A relatively long-term residual effect of ivermectin on migrating larvae is indicated by the significantly lower number of larvae detected in the lungs of ivermectin-treated pigs not exposed to parasites following a challenge inoculation (Group D vs Groups A and G following a primary exposure of 10,000 eggs; Table 3). The residual effects of both anthelmintics on migrating larvae of *A. suum* also are implicated by the relatively low number of adults in the intestine at the time of necropsy. Fenbendazole was effective against *A. suum* larvae (Stewart et al., 1984); the efficacy of ivermectin against migrating *A. suum* larvae has not been reported. Both anthelmintics are highly effective against *A. suum* adults (Marchiondo and Szanto, 1987). The efficacy of ivermectin against adult *T. suis* (Stewart et al., 1981; Schillhorn-van-Veen and Gibson, 1983) is dubious; this is apparent from the similar number of adult *T. suis* detected at necropsy in pigs exposed to the parasite in dirt lot (Table 4). Alternatively, immunity could have contributed to the reduced adult recoveries of *A. suum* at the end of both Phase 1 (Table 4) and Phase 2 (Table 5), as the effective drug concentration in the tissues waned temporally in the face of continual parasite exposure.

It was somewhat surprising that any adult *A. suum* were present in pigs at the end of Phase 2, given the high level of protective immunity (>99%) that was observed at the end of Phase 1. A degree of protective immunity was still evident in the parasite-exposed groups (B, C, E, F, H and I) at the end of Phase 2 because of the reduced liver pathology (white spots and fibrosis) observed following a challenge-exposure of 1,000 eggs compared with control pigs (Groups A, D and G). It had been observed previously (Lunney et al., 1986)

that liver pathology was reduced in pigs following 6 wk of chronic exposure to *A. suum* and an immediate challenge inoculation with 10,000 eggs. Together, these results indicate that immunological memory is functionally expressed after 6 wk of chronic parasite exposure for at least 10 to 12 wk (the period between Phase 1 and the end of Phase 2). In other experiments, when pigs were exposed continually to *A. suum* for 12 wk then challenge-exposed to 10,000 eggs, a sterilizing immunity had apparently developed, because there was no larval migration to the lungs, no liver pathology and an intestinal barrier to larval penetration had been established (Urban et al., 1988). The intestinal mucosa of these pigs contained relatively large numbers of eosinophils and mast cells, and a thickened tunica muscularis (Stephenson et al., 1980; Urban et al., 1988). However, when pigs are chronically exposed for 12 wk, then maintained with no parasite exposure for 1 mo, followed by a challenge exposure to 10,000 eggs, sterilizing immunity was reduced because liver pathology (white spots) increased (Urban, unpublished data). Therefore, it appears that periodic immunology boosting and(or) anthelmintic dosing will be required during the growing-finishing period if complete removal of adult *A. suum* and minimal liver pathology are goals.

There were several interesting observations made on growth performance in Phase 2. The six groups that had been maintained on concrete throughout the experiment (groups A, B, D, E, G and H) had similar mean body weights and ADG during Phase 2, regardless of prior parasite exposure, anthelmintic treatment or adult *A. suum* worm burdens. Others have shown that adult *A. suum* worm burdens affect the growth performance of growing-finishing pigs only when protein in the diet is limited (Zimmerman et al., 1973; Stephenson et al., 1980; Forsum et al., 1981). Significant differences in mean body weights and ADG only were observed in pigs from Group C that had been naturally exposed to parasites on dirt and had not been treated with anthelmintic. This condition apparently was corrected by two strategic applications of either ivermectin (Group F) or fenbendazole (Group I), because both Groups F and I had no significant difference in mean body weight and ADG from pigs raised on concrete, albeit their ADG were lower. The simple explanation of this observation is that minimizing parasite migration and lowering adult worm burdens positively affected growth. However, Group B also experienced chronic larval migration from experimental inoculations and had a relatively large population of *A. suum* adults without exhibiting poor performance.

Pigs on the dirtlot had been exposed not only to *A. suum* but also to the swine whipworm, *T. suis*, which also has been shown to negatively affect swine growth rate (Hale and Stewart, 1979). In addition, there was evidence of secondary microbial infections in pigs maintained on the dirtlot. Four of 18 barrows maintained on dirt in Phase 1 had visually detectable abscesses in their mesenteric lymph nodes at slaughter (one animal's carcass was condemned), whereas only one of 36 pigs maintained on concrete had detectable abscesses. Further, the only death record in Phase 2 was from pleuritis and pneumonia in one pig from the dirtlot. The effects of these secondary infections on pigs maintained on dirt may have been exacerbated by the persistence of adult parasites in pigs from Group C, resulting in poorer performance than their counterparts that had been treated with anthelmintic (Groups F and I).

The reduced ADG exhibited by pigs from Group C under the uniform management and nutritional conditions of Phase 2 indicates that growth potential was damaged permanently from earlier parasite exposure on dirt without anthelmintic therapy. Any compensatory growth that may have occurred could have been in the form of a higher and disproportionate organ to body mass growth; diet utilization may have been for maintenance and visceral growth but not for additional muscle tissue. Although these parameters were not examined in the current study, Stephenson et al. (1980) have demonstrated an increase in intestinal smooth muscle, wet and dry, weight in pigs infected with adult *A. suum*. Stewart et al. (1984) have observed an increase in the proportion of lung weight to body weight following parasitic larval migration.

In summary, this study has differentiated the effects of management environment and pharmacological strategies used to combat intestinal parasitism of swine related to immune system function and the subsequent effects on rate and efficiency of growth. The most efficacious method to minimize effects of intestinal parasitism appears to be stringent

control over environmental contamination, and the strategic application of pharmacological agents to combat adverse long-term effects of infection.

Literature Cited

Barr, A. J., J. H. Goodnight, J. P. Sall and J. T. Helwig. 1976. SAS User's Guide. SAS Inst., Inc., Cary, NC.

Biehl, L. G. 1982. Common internal parasites of swine. Vet. Clin. North Am. 4:355.

Biehl, L. G. 1986. Anthelmintics for swine. Vet. Clin. North Am Food Anim. Pract. 2:481.

Douvres, F. W., F. G. Tromba and G. M. Malakatis. 1969. Morphogenesis and migration of Ascaris suum larvae developing to fourth stage in swine. J. Parasitol. 55: 689.

Forsum, E., M. C. Nesheim, and D.W.T. Crompton. 1981. Nutritional aspects of *Ascaris* infection in young protein-deficient pigs. Parasitology 83:497.

Froe, D. L. 1982. Ascarid larval migration. Mod. Vet. Pract. 63:829.

Hale, O. M. and T. M. Stewart. 1979. Influence of an experimental infection of *Trichuris suis* on performance of pigs. J. Anim. Sci. 49:1000.

Hale, O. M., T. B. Stewart, O. G. Marti. 1985. Influence of an experimental infection of *Ascaris suum* on performance of pigs. J. Anim. Sci. 60:220.

Jakovljevic, D. D. 1975. Some aspects of the epizootology and economical significance of ascariasis in swine. Acta Vet. (Belgrad.) 25:315.

Lunney, J. K., J. F. Urban, Jr. and L. A. Johnson. 1986. Protective immunity to *Ascaris suum:* Analysis of swine peripheral blood cell subsets using monoclonal antibodies and flow cytometry. Vet. Parasitol. 20:117.

Marchiondo, A. A. and J. Szanto. 1987. Efficacy of dichlorvos, fenbendazole and ivermectin in swine with induced intestinal nematode infections. Am. J. Vet. Res. 48:1233.

Murrell, K. D. 1986. Epidemiology, pathogenesis, and control of major swine helminth parasites, Vet. Clinics North Am. Food Anim. Pract. 2:439.

Nilsson, O. 1982. Ascariasis in the pig: An epizootiological and clinical study. Acta. Vet. Scan. Suppl. 79:1.

NRC. 1979. Nutrient Requirements of Swine. (8th Rev. Ed.). National Academy Press, Washington, DC.

Roneus, O. 1966. Studies on the aetiology and pathogenesis of white spots in the liver of pigs. Acta Vet. Scand. Suppl. 16:1.

Schillhorn-van-Veen, T. W. and C. D. Gibson. 1983. Anthelmintic activity of ivermectin in pigs naturally infected with *Ascaris* and *Trichuris*. Am. J. Vet. Res. 44:1732.

Spindler, L. A. 1947. The effect of experimental infections with ascarids on the growth of pigs. Proc. Helminthol. Soc. Wash. 14:58.

Stephenson, L. S., W. G. Pond, M. C. Nesheim. L. P. Krook and D.W.T. Crompton. 1980. *Ascaris suum:* Nutrient absorption, growth and intestinal pathology in young pigs experimentally infected with 15 day old larvae. Exp. Parasitol. 49:15.

Stewart, T. B., G. Batte, H. E. Connell, R. M. Corwin, D. L. Ferguson, H. R. Gamble, K. D. Murrell, A. K. Prestwood, B. P. Stuart, F. G. Tromba and B. E. Wheat. 1985. Research needs and priorities for swine internal parasites in the United States. Am. J. Vet. Res. 46: 1029.

Stewart, T. B., T. D. Bidner, L. L. Southern and L. A. Simmons. 1984. Efficacy of fenbendazole against migrating *Ascaris suum* larvae in pigs. Am. J. Vet. Res. 45:984.

Stewart, T. B., O. G. Marti and O. M. Hale. 1981. Efficacy of ivermectin against five genera of swine nematodes and the hog louse, *Haematopinus suis*. Am. J. Vet. Res. 42: 1425.

Urban, J. F., Jr. 1985. The epidemiology and control of swine parasites: Immunity and vaccines. Vet. Clin. North Am. Food Anim. Pract. 2:765.

Urban, J. F., Jr., F. W. Douvres and F. G. Tromba. 1981. A rapid method for hatching *Ascaris suum* eggs in vitro. Proc. Helminthol. Soc. Wash. 48:241.

Urban, J. F., Jr., and R. D. Romanowski. 1985. *Ascaris suum:* protective immunity in pigs immunized with products from eggs and larvae. Exp. Parasitol. 60:245.

Urban, J. F., Jr., H. A. Alizadeh and R. D. Romanowski. 1988. *Ascaris suum:* development of intestinal immunity to infective second-stage larvae in swine. Exp. Parasitol. 66:66.

Zimmerman, D. R., M. L. Spear and W. P. Switzer. 1973. Effect of *Mycoplasma hyponeumoniae* infection, pyrantel treatment and protein nutrition on performance of pigs exposed to soil containing *Ascaris suum* ova. J. Anim. Sci. 36:894.